CYCLE-TIME SIMULATION FOR A MULTIPRODUCT MANUFACTURING FACILITY

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Abstract

This is a generalized simulation model for a multiproduct manufacturing line with interdependent production equipment. Based on various product demands, it simulates resources such as manpower and equipment and generates product cycle time. It is a deterministic model. It takes into consideration equipment reliability, man-machine interactions, yields, rework, and process-related constraints. The model could also be used to plan resource requirements to fulfill required product cycle times. The model is written in GPSS language with PL/1 subroutines. The temptation to include relatively less pertinent factors is resisted in order to keep the model economical.

INTRODUCTION

The successful commitment of resources is one of the most crucial responsibilities plant management faces. This is particularly true in the semiconductor business, where new products are introduced at an ever-increasing pace from laboratories, and new product applications create modifications of current products. These factors -- and the spur of competition -- make product manufacturing cycle time more important than ever.

The cycle time to manufacture a product is affected by three major factors: equipment, human resources, and buffer or work in process. The dynamic nature of business is very complex, however, due to many variables: demand fluctuations, change in product mix, addition of new products, variation in number and types of manufacturing operations for different products, variation of process times for operations from several minutes to several hours, batch type and individual unit operations, and variation of batch size by operation.

To gain insight into such complexities and an understanding of interrelationships is beyond the capability of one person without the aid of some meaningful tool. Simulation is one of the most exciting techniques employed. When enhanced by high-speed computers, simulation makes it possible to tackle complex problems in very short times. It also deals with dynamics. The real-world complexities can be closely represented in a physical model on paper. Manipulation of the model for different strategies enables management to find out what the probable results would be, and thus leads to making sound business decisions before actually committing the resources.

This paper describes a fairly complex, deterministic simulation model of a multiproduct manufacturing facility. The model was developed primarily to better understand the interrelationships of the complexities of the manufacturing floor and to reduce the product manufacturing cycle time. Such insight permits faster manufacturing response and a reduction in time and cost when introducing product changes. An independent, controlled experiment carried out on the manufacturing floor helped to validate the model by achieving results on the floor. The combined efforts of model and experiment led to a reduction in product queueing times by 66 percent.

Depending on the basic information and the end result sought after, the model can give product cycle time based on the available resources, or the resources required to meet the planned cycle times. The impact of a proposed engineering change or group of changes can be meaningfully analyzed. The model is not designed to give the global optimum solution in one exercise, but can lead to a nearly optimal solution by iteration. The economics in terms of dollars and cents has to be evaluated externally for the different iterations.

The model enables management to analyze the impact of the following manufacturing parameters: 1) daily schedule start by product, 2) product route and modifications, 3) rework loop or loops, if any, and different rework percentages of virgin products, 4) equipment plans, 5) manpower and productivity, 6) job enlargement, 7) production losses or yields by operation or group of operations, 8) operation-level time parameters, i.e., unit or batch process time, 9) reliability and maintainability of equipment, and 10) plant operation policy for shifts, working days per week, etc.

The model is a generalized one to simulate most discrete manufacturing facilities. It is designed to provide a general framework for simulating the flow of jobs through a manufacturing facility using specified equipment, manpower, and buffer (WIP) resources. The model is written in GPSS-V language with PL/1 subroutines. The PL/1 subroutines are used for two purposes: for ease of input data manipulation, and for GPSS output report summarization and interpretation. A typical system requirement for ten products having a routing of 90 to 300 operations and about 350 pieces of equipment can be about 400K bytes of core space. To simulate two months of manufacturing activity for the situation just described can take about 25 min of CPU time on a System/360 model 85 computer. It is essential that the simulation time be long enough to reach steady-state conditions.

The outline of the model structure and its salient features are presented here.

MANUFACTURING CYCLE TIME

The cycle time of a product consists of the actual time to process for each operation, the waiting time before each operation, and the transfer time between operations.

Reliability of the equipment also has an impact on the cycle time and buffer requirements. To maximize utilization of equipment and people usually requires large buffer volumes, which leads to longer cycle time. Immediate implementation of a mandatory product change becomes very costly because of the scrapping of large buffer volumes.

Figure 1 presents a sketch of a unique manufacturing plant segment. Say there are 5 products, 8 operations, and 32 pieces of equipment, within 12 equipment groups. Let A-E represent the products and 1-8 represent the operations. The schematic shows the product dedication by equipment group for each operation, as well as the rework path. Any discrete manufacturing facility could be represented similarly by a schematic drawing for simulation studies.

MANUFACTURING LINE REPRESENTATION

Figure 2 represents the system and logic modules, which are described below.

Facility Representation

Physical realities of a manufacturing plant are closely represented in the model by equipment groups by departments or segments of a department.

Equipment Parameters

Each equipment group can be given two parameters, for planned and unplanned downtime or maintenance. The planned downtime can be specified as a fixed-time activity for one of the periods, such as, each shift, each day, or each week, etc. By scheduling downtime, it is possible to reflect start-up activity, periodic instrument calibration, etc. Unplanned maintenance can be specified by two factors: mean time between failure (MTBF) and mean time to repair (MTR). Each factor can be either of fixed time value or a mean value of a statistical distribution with its variance.

Manpower

Manpower is assigned by a manpool, which provides service to given equipment groups based on skill and training. The man-machine relationships, such as one man per machine, one man for more than one machine, and more than one-man crew per machine, can be specified. Here, job enlargement policies to eliminate monotonous activities can be studied.

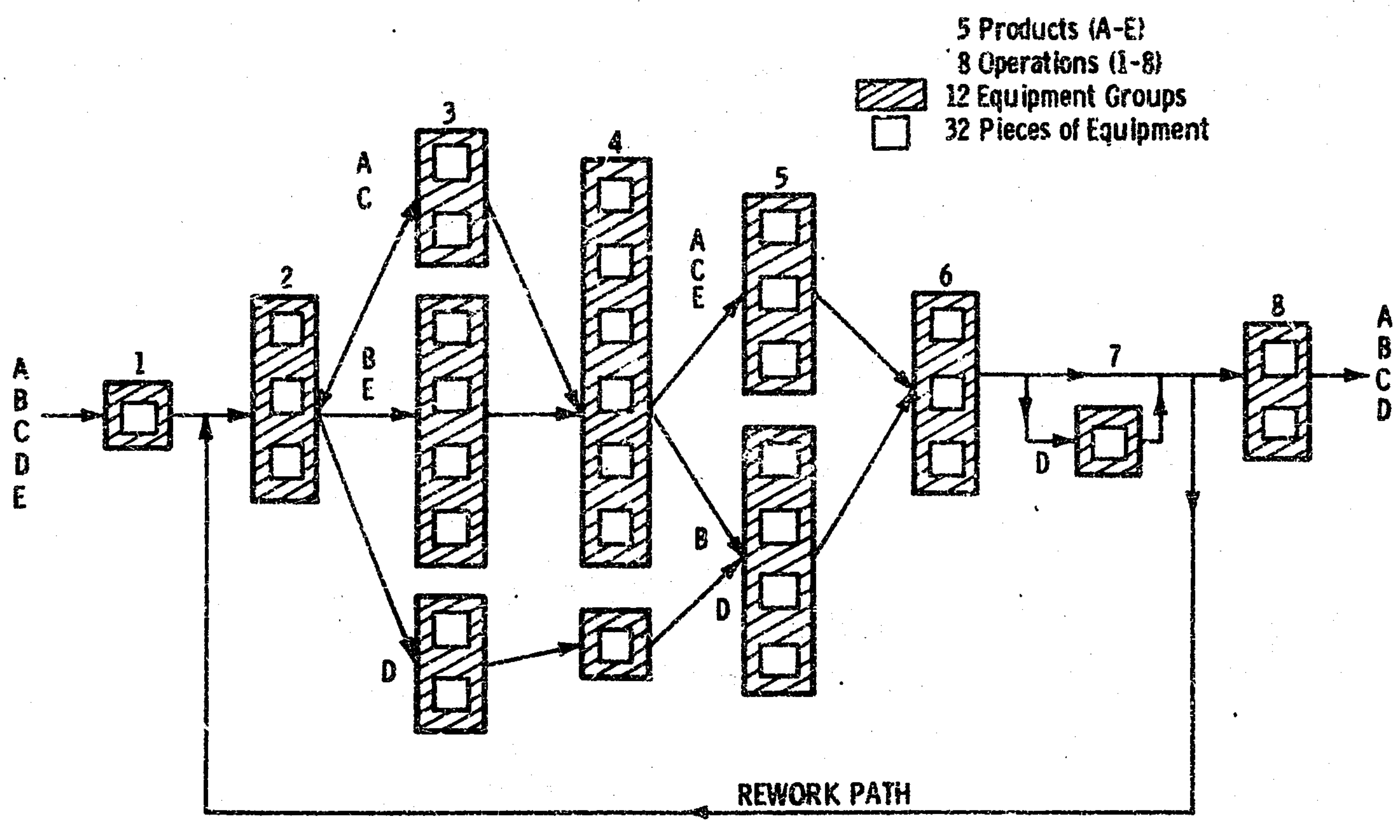

Fig. 1. Schematic of a unique factory segment.

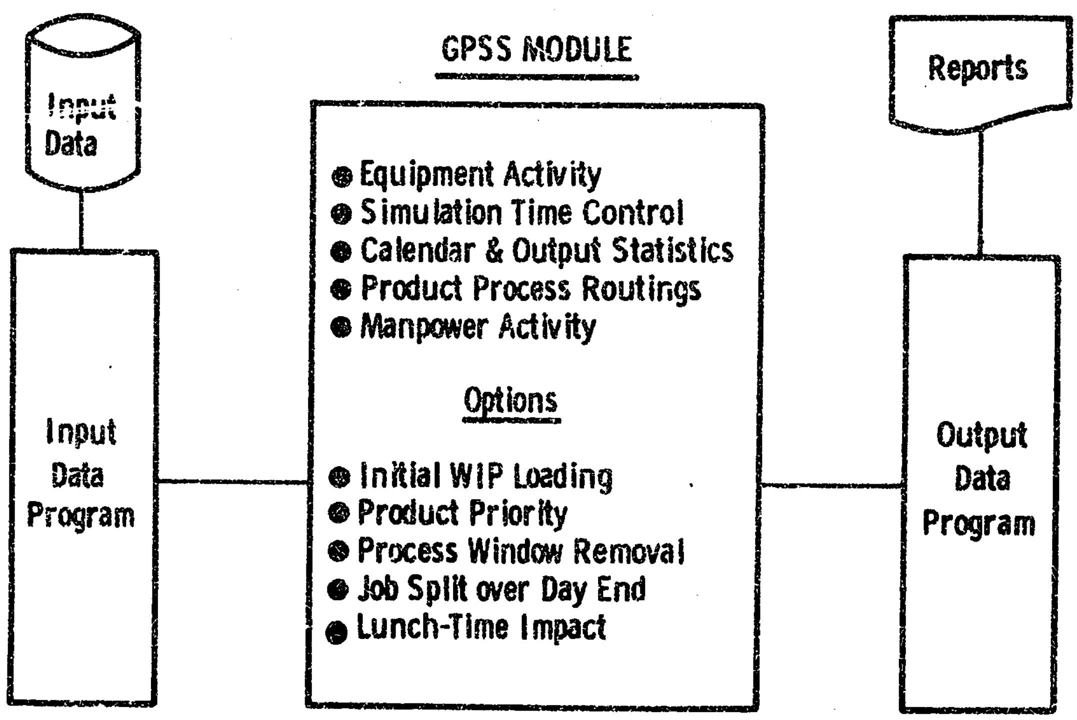

Fig. 2. System and logic modules.

Staggered lunch periods for certain operation coverage can be realized by using a cafeteria log algorithm. For example, where cafeteria service is available between 11 a.m. and 1 p.m. for the morning shift and the lunch period is for one-half hour, an operator would go to lunch within the cafeteria service time depending on the product flow and the process time for a given operation.

Process Routings

Each product has detailed process routings for sequential virgin operations and rework paths, as required. Two types of rework paths can be specified, as shown in Fig. 3. The rework is given as a percentage of the jobs for each path. Also, the maximum number of times a job can be reworked at an operation can be specified.

Operation Parameters

Each operation can be given three time parameters, two for process time (A and B) and the third for manpower (C). The use of two process parameters permits a single-step or multiple-step process to be represented. A single-step process, such as inspection, testing, baking, milling, etc., is shown in Fig. 4. Multiple-step processes such as chemical clean-rinse-dry, progressive drawing, bearing cage stamping, multiple-pass grinding, etc., can be represented as shown in Fig. 5. In such cases, parameter A is the time interval for a unit or batch to enter the system, and parameter B is the remaining time a unit or batch has to spend in the system.

An outline of the basic job flow is shown in Fig. 6.

Work-Time Policy

The work time policy can be specified for the following:

- Working hours per shift.
- Number of shifts per day.
- Number of working days per week.
- Number of weeks in a period.
- Number of periods to be simulated.

Process Window

The program takes into consideration whether a job can be finished before the end of the working day. If the available time is less than the process time, then the job waits until the next day or is processed on overtime.

MODEL OPTIONS

Buffer/WIP

Initial buffer distribution by process step by product can be assigned as an input or the model can be run without it.

Product Priority

If desired, priority can be assigned to a product or group of products. Otherwise, the model will handle buffer and the released products on a FIFO (first-in, first-out) basis.

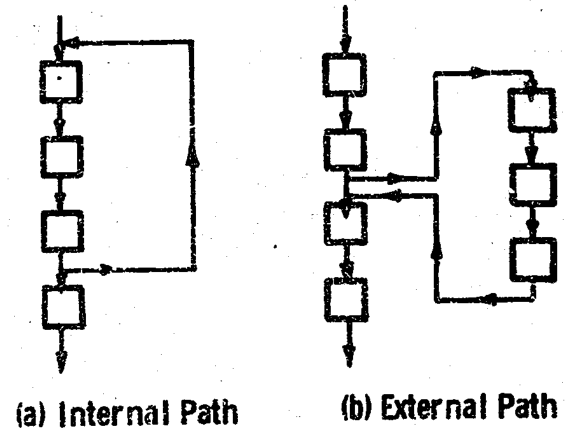

Fig. 3. Rework paths.

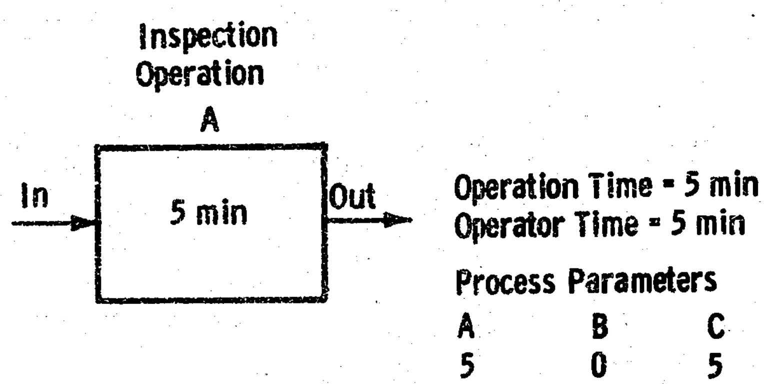

Fig. 4. Single-step operation.

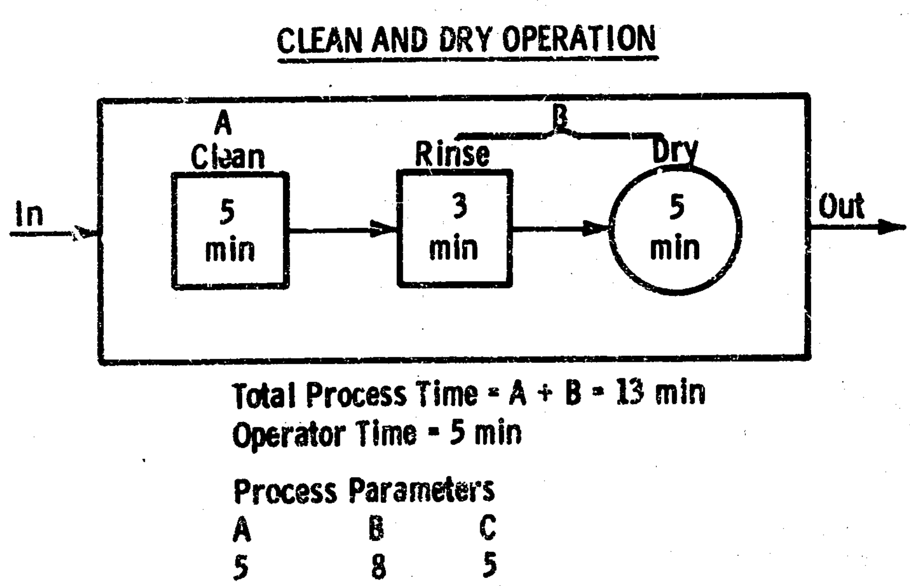

Fig. 5. Multiple-step operation.

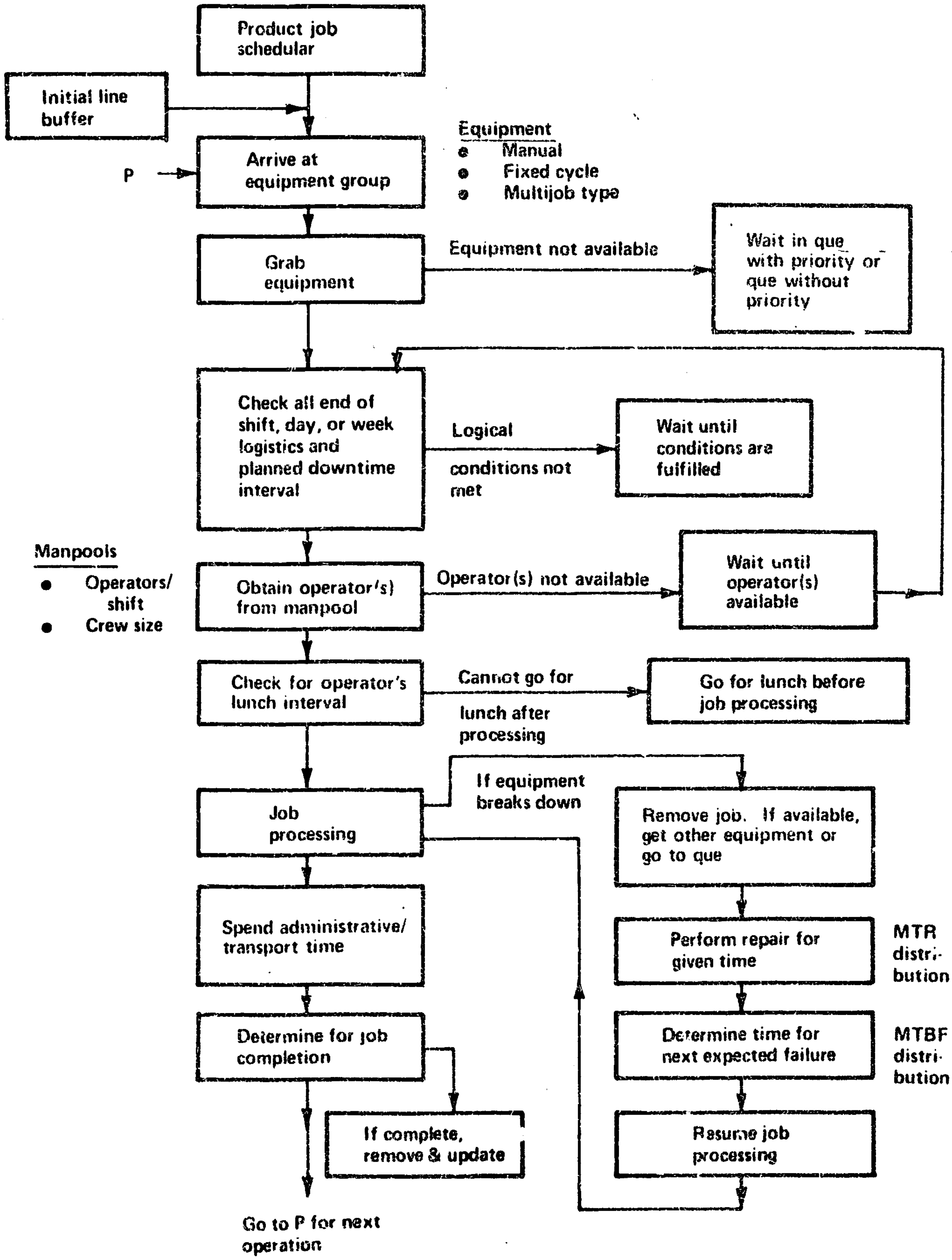

Fig. 6. Basic job flow.

Process Window Removal

On equipment with uniterruptable process time, this option enables a plant to get one extra batch a day per piece of equipment specified. Maximum over-time in such cases would be equal to the 'process time' by processes by pieces of equipment.

Lunch Time

Depending on the manufacturing environment, this option can be exercised or not in the simulation model.

Job Split

This is useful when a product is released in a lot size of 50, 100, or any number of units, and in some operations performed on a unit basis. Use of this option permits partial processing of a lot at the end of a working day and the remainder on the following working day.

Manpower

The input subroutine program can compute manpower by pool by shift based on the release schedule, or it can be preassigned in the input data.

OUTPUT REPORTS

The contents of the output reports are designed to give only pertinent data to facilitate decisions for all levels of management. They are enumerated as follows:

1. Total jobs and quantities released at the first operation, and jobs and quantities placed in stock by period by product.
2. Sector or segment and over-all cycle-time mean with standard deviation, and sector raw process time (i.e., sum of each operation's process time in the sector) by product.
3. Equipment group utilization and maximum queue buildup.
4. Manpool and over-all manpower utilization.
5. Buffer/WIP distribution in line by operation by product.

CONCLUSIONS

The simulation system described in this paper can be used as a tool to aid plant management in evaluating alternative strategies, where selection of equipment, manufacturing processes, new facility design, or modification of existing facility is involved and short cycle times are required. The immediate management responsible for production can visualize the impact of job enlargement, process step modifications and/or eliminations, different levels of manpower and equipment utilizations, and product volumes, on cycle time.

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